The Scientific Role of the Space Telescope Imaging Spectrograph after SM4

Charles R. Proffitt[1], C. Leitherer[2], A. Aloisi[3], L.L. Dressel[2], P. Goudfrooij[2], M.E. Kaiser[4], G.A. Kriss[2], J. Maíz Apellániz[5], K.R. Sembach[2], and M.A. Wolfe[2]

[1]STScI/CSC, [2]STScI, [3]STScI/ESA, [4]JHU, [5]Instituto de Astrofísica de Andalucía, Spain.

SPACE TELESCOPE SCIENCE INSTITUTE
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Abstract: The Hubble Space Telescope's Space Telescope Imaging Spectrograph (STIS) was one of the most heavily utilized of HST's instruments from the time of its installation in 1997 until it suspended operations in August 2004. Plans for the next Hubble Space Telescope (HST) Servicing Mission (SM4) include a repair of STIS, and should return it to operations with capabilities similar to those it had before the 2004 failure. Even with the availability of Wide Field Camera 3 (WFC3) and the Cosmic Origins Spectrograph (COS), which are also slated to be installed during SM4, STIS will retain a number of unique capabilities that will make it the instrument of choice for many science programs. Here we briefly summarize some of these abilities, and give examples of the kinds of science programs that might benefit from using STIS.

Unique capabilities of STIS include:

(1) High spatial resolution, long slit, 1st order spectra at wavelengths ranging form 1140 Å to 10,200 Å. (COS has more limited capabilities for obtaining spatially resolved UV spectra, and has no capability at optical wavelengths).

STIS MAMA First Order Gratings Spatial scale of ~0.0245″ - 0.024″/pixel over 25″ - 29″long slit			
Grating/ Prism	Wavelength Range (Å) Full	Å per tilt	Resolving Power (λ/Δλ)
G140L	1150 - 1730	580	934 - 1440
G140M	1150 - 1740	55	11,500 - 17,400
G230L	1570 - 3180	1610	500 - 1005
G230M	1640 - 3099	90	9100 - 17,500
PRISM	1150 - 3000	1950	2500 - 10
STIS CCD First Order Grating Spatial scale of ~0.051″/pixel over 52″ long slit			
G230LB	1685 - 3175	1380	615 - 1135
G230MB	1640 - 3190	155	5550 - 10,335
G430L	2900 - 5700	2800	530 - 1040
G430M	3025 - 5615	286	5330 - 10,270
G750L	5240 - 10,270	5030	535 - 1170
G750M	5450 - 10,200	570	4870 - 9950

(2) STIS high resolution echelle gratings can obtain UV spectral resolution in excess of 100,000. (Maximum for COS is R ~ 20,000).

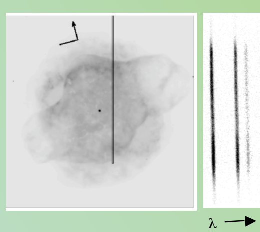
MAMA Echelle Gratings			
Grating	Wavelength Range (Å) Full	Å per tilt	Resolving Power (λ/Δλ)
E140M	1150 - 1700	550	45,800
E140H	1150 - 1700	210	114,000
E230M	1575 - 3100	800	30,000
E230H	1650 - 3000	267	114,000

(3) S/N ratios in excess of 100:1 per resolution element can routinely be obtained for most STIS spectroscopic modes. It has also been shown that by employing specialized observing techniques, differential measurements using the STIS CCD can obtain S/N ratios as high as 10,000:1 (Gilliland et al. 1999, PASP 111, 1009).

Extra-solar Planets: Detection and analysis of the faint atmospheric absorption of a transiting extra-solar planet against the stellar light requires both extremely high S/N and high confidence in the sky subtraction. The very high differential S/N ratios that can be achieved with the STIS CCD when combined with the STIS long-slit capabilities make STIS an ideal instrument for studying these objects.

Stellar Jets and Ejecta: Stellar ejecta around individual stars are often highly structured, and may be chemically differentiated. Planetary nebulae in particular preserve a record of the late stages of a star's mass loss. UV lines are essential for calculating the abundances of the element related to stellar evolution (C, N, O) and to progenitor populations (e.g., Ne). Spatially resolved STIS long-slit UV spectroscopy of PNs with known morphology and central star properties were planned for Cycle 13, but had not yet executed prior to the failure of STIS.

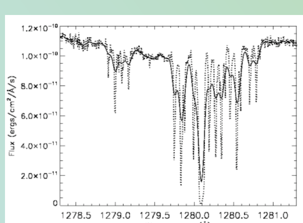
The figure below shows the placement of the STIS long slit that was used to obtain spatially resolved observations of the quadrupole, intercombination, and hyperfine components of the N IV 1487.9 Å line in the planetary nebula NGC 3918 by Brage, Judge, & Proffitt 2002 (Phys. Rev. Let., 89, 1101). This observation validated the theoretical calculations for the transition rate of this hyperfine component. Observations of similar hyperfine components of C III and Si III would allow the measurement of isotopic ratios in low density planetary nebulae.



Left: WFPC2 image of NGC 3918 with STIS position of STIS 52x0.2 aperture shown.

Right: Corresponding two-D G140M spectral image of the 3 components of the N IV 1487.9 Å line in this PN.

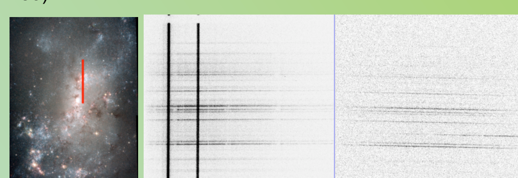
ISM/IGM: Accurate determinations of the abundances and physical conditions of the interstellar and intergalactic gas rely upon high-resolution absorption-line observations. The ability to determine accurate abundances and physical conditions improves greatly when the lines are resolved, or close to being resolved, by the instrument. For most interstellar environments, the lines have intrinsic widths of a few km/s and turbulent broadening widths of several km/s. This means that resolutions comparable to those afforded by the STIS echelles (R ~ 45,000 - 100,000) are necessary to perform the best possible abundance analyses and physical condition determinations. In the figure below, we show an example of an interstellar C I multiplet in the spectrum of HD 210839 observed using the E140H (see Jenkins & Tripp 2001, ApJ 137, 297). With STIS (dotted line), these lines are fully resolved, but at a resolution of 20,000 (solid line), many of these features would be blended together.



Detail of a STIS E140H spectrum of HD 210839. The dotted line shows the observed STIS spectrum. The solid line shows the same spectrum degraded to a resolution of R = 20,000, equivalent to that of the COS medium resolution modes.

The superior resolution of the STIS echelles will also be essential for the interpretation of absorption lines of ionized species in the IGM. At a temperature of 10^4 K, the thermal width (FWHM) of a C IV absorption line is only 6.2 km/s. Being able to fully resolve these lines with STIS without the need for an instrumental resolution correction would greatly benefit future COS analyses of similar systems, and will also have important ramifications for complementary studies of the baryonic content of the low-redshift universe and the distribution of metals within the IGM.

Galaxies: The ability of the STIS long slits to produce spatially resolved spectra could play a pivotal role in improving our understanding of many aspects of both normal and active galaxies, allowing improved measurements of stellar populations and kinematics in these objects. STIS can be a useful complement to even the largest ground based telescopes when observing stellar clusters near the centers of complex objects such as merger remnants or starburst galaxies, as STIS enables much better background subtraction: (i) a narrow slit reduces background contamination by a factor of ~ 10 relative to ground based spectra; (ii) the ground-based spatial resolution is not adequate to obtain good background subtraction; (iii) STIS has high sensitivity below 4200 Å where the crucial high-order Balmer lines are located. In the starburst galaxy NGC 4449, a STIS long slit was used with the G140L and G230L gratings to obtain spectra of both stellar clusters and field stars which clearly showed distinct differences between the cluster and field populations (see Chandar et al. 2005, ApJ, 628, 230).



Left: ACS/WFC image of NGC 4449 with STIS 52X0.2 slit position overlaid.

Right: STIS G140L and G230L spatially resolved spectra at this slit position.

Black Hole Physics: The high spatial resolution and spectroscopic capability of STIS has enabled the bulk of the work done on supermassive black holes in the nuclei of nearby galaxies since 1997, when STIS was installed in HST. Large ground-based telescopes with adaptive optics and the use of laser guide stars hold promise for the future, but at present the critical resolution of a few parsecs with a stable PSF at the center of nearby galaxies is unobtainable with any spectrograph but STIS. While many such targets have been studied using STIS, the application of improved observational techniques with STIS would especially benefit spatially resolved spectroscopy of nuclear emission-line disks in Keplerian motion. More measurements at the extremes of the mass distribution of galaxies are also needed; indeed, several such programs were approved but not done in Cycle 13.